REVITALISATION OF ORGANIC AND PEAT SOILS

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Dedicated especially towards my loving parents,

Mr. and Mrs Tang,

and beloved siblings,

Thank you for always being there for me.

Without your support this would mean nothing

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ABSTRACT

Ground improvement projects are often necessary and site – specific to ensure project success. The author hypothesizes that problematic soil, which are often mass replaced can be revitalised with modest proportions (<10%) of Ordinary Portland Cement as a binder to make a positive contribution to economic, green engineering, and resource sustainability. Deep cement mixing (DCM) techniques have proved to be successful worldwide and use large proportions (circa 200%) of cement, lime and/or fly ash in dry or wet mixing to form in-situ piles with enhanced strength and stiffness in comparatively short time. Revitalisation of organic and peat soils is not a practice currently adopted in Malaysia which has a distribution of over 1.5 million ha of such challenging soils. Such soils have high water and organic content and their mechanical chemical and biological properties degenerate with time. Land shortage for development promotes land reclamation. The shear strength and stiffness behaviour of these heavily organic soils and the revitalised soils is central to this research study. Peat soil from Pontian, Johor and an organic soil from Bukit Rambai, Malacca are investigated with laboratory controlled cement slurry mixing at water cement ratios of 3.5,7,14,140 for peat and 5,10,15 for organic soil. Specimens of these soil mixtures were prepared in polyvinyl chloride tubes (50 mm diameter 300 mm long) and cured at room temperature of 25^{o}C and relative humidity of 50% for 7,14 and 28 days. Unconfined compressive strength, consolidated undrained triaxial, bender element, and one dimensional consolidation tests were done to assess the strength and stiffness improvements of the 'revitalised soils'. Increases of up to 30% and 16% in unconfined compressive strength and 229% and 0.9% in G_o for Pontian Peat and Malacca organic soil respectively are reported in this study.

Keywords: cement slurry**,** organic soils, peat soils, revitalisation, strength, stiffness.

ABSTRAK

Projek pembaikan tanah sering diperlukan dan tapak - khusus bagi memastikan kejayaan projek. Penulis menghipotesis bahawa tanah bermasalah, yang sering digantikan atau ditambak boleh digiatkan semula dengan hanya menggunakan simen (OPC) dalam kadar yang sederhana (<10%). Simen bertindak sebagai pengikat yang mana juga boleh memberi sumbangan positif kepada ekonomi, kejuruteraan hijau, dan kelestarian sumber. Teknik 'Campuran Simen Dalam (DCM) telah terbukti kejayaannya di seluruh dunia. Sebahagian besar (sekitar 200%) simen, kapur dan abu terbang samaada dalam bancuhan kering atau basah digunakan untuk membentuk cerucuk di tapak untuk meningkatkan kekuatan dan kekukuhan tapak dalam jangka masa yang pendek. "Proses mengiat semula" tanah organik dan tanah gambut bukan merupakan satu amalan biasa di negara Malaysia yang mana tanah yang mencabar ini meliputi 1.5 juta hektar. Tanah tersebut mengandungi kuantiti air dan organik yang tinggi dan ciri- ciri mekanik, kimia dan biologi merosot mengikut masa. Kekurangan tanah untuk pembangunan menggalakan teknik penambakan tanah. Kelakuan kekuatan ricih dan kekakuan tanah berorganik tinggi dan tanah digiat semula ini adalah penting dalam kajian penyelidikan ini. Tanah gambut dari Pontian, Johor dan tanah organik dari Bukit Rambai, Melaka digunakan dalam kajian ini. Bancuhan basah simen pada nisbah air simen 3.5, 7, 14, 140 untuk tanah gambut Pontian, manakala nisbah air simen 5,10,15 untuk tanah organik digunakan. Spesimen kajian telah disediakan dalam tiub polyvinyl chloride (PVC) (bergaris pusat 50 mm dan 300 mm panjang) dan diletakkan dalam kotak pada suhu bilik 25^{o}C dan kelembapan bandingan 50% untuk jangka masa 7, 14 dan 28 hari. Ujikaji kekuatan mampatan tak terkurung, ujian pengukuhan tak tersalir, elemen bender dan pengukuhan telah dijalankan untuk mengkaji pembaikan kekuatan dan kekakuan tanah yang digiat semula. Peningkatan kekuatan tak terkurung masing –masing sebanyak 30% dan 16% dan sebanyak 229% dan 0.9% G_o untuk tanah gambut Pontian dan tanah organik Melaka telah dilaporkan pada kajian ini.

Kata kunci: Simen buburan, tanah organik, tanah gambut, proses mengiat semula, kekuatan, kekakuan.

TABLES OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF NOTATIONS AND ABBREVIATIONS

a	binder factor
Al_2O_3	aluminium oxide
a_w	binder content
ASTM	American Society for Testing and Materials International Standard
A	Skempton A parameter
B	saturation ratio (Skempton)
BE	bender element
BS	British standard
^oC	degree celsius
CaO	calcium oxide
C_c	compression index
Cc	coefficient of curvature
Ca^+	Calcium
CH	calcium hydroxide
CSH	Calcium silicate hydroxide
CAH	Calcium aluminate hydroxide
C_3S	Tricalcium silicate
C_2S	Dicalcium silicate
C_3A	Tricalcium aluminate
C_4AF	Tetracalcium aliminoferrite
Cl	chlorine
COO^-	carboxylic acid
C_r	recompression index
C_s	swelling index
C_u	uniformity coefficient
C_g	coefficient of gradation
CU	consolidated undrained triaxial
d	day
D_n	grain diameter at n percent finer diameter
DCM	Deep cement mixing
e	void ratio
e.g.	for example
et al.	and other people
E	young modulus
ET	ettringite
Fe_2O_3	feric oxide
FTIR	fourier transform infrared spectroscopy
g	gravity
G_o	small strain shear modulus
G_s	specific gravity
HCl	hydrogen chloride
HF	hydrogen fluoride
HNO_3	nitric acid

i.e.	that is
LL	liquid limit
log	logarithm
M	original organic soil
MARDI	*Malaysian Agricultural Research and Development Institute*
MID-IR	Mid- Infrared (Majority of FTIR applications)
Mn	organic soil with n percent of cement
MOS	Malacca organic soil
m_v	coefficient of volume change
N	standard penetration resistance
NA	not available
OC	organic carbon
OPC	ordinary Portland cement
P	original peat soil
pH	a measurement of the acid or alkaline level
PI	plasticity index
PL	plastic limit
Pn	peat soil with n percent of cement
ppm	parts-per-million, 10^{-6}
PP	Pontian peat
PVC	polyvinyl chloride
RECESS	Research Centre for Soft Soil
RM	Ringgit Malaysia
SEM	scanning electron micrograph
SiO_2	silica dioxide
SO_3	sulfur trioxide
SPT	standard penetration test
Sr	degree of saturation
TOC	total organic carbon
UCS	unconfined compressive strength
USCS	unified soil classification systems
UTHM	Universiti Tun Hussein Onn Malaysia
V	volume
V_p	compression wave velocity
V_s	shear wave velocity
XRD	X- ray diffraction
XRF	X-Ray fluorescence
w	water content
w_i	initial water content
W_T	weight of soil
W_B	weight of binder
W_s	dry weight of soil
w:c	water cement ratio
u_b	back pressure
ZnO	zinc oxide
γ	Unit weight
kPa	pressure

LIST OF APPENDICES

REVITALISATION OF ORGANIC AND PEAT SOILS

CHAPTER 1
INTRODUCTION

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INTRODUCTION

1.1 Research context and problem statement

Tropical peat lands occur throughout the tropics. However in Malaysia alone there is about 1.54 million hectares, of which about 13 % are in peninsular Malaysia, over 80 % in Sarawak and about 5 % in Sabah (Ongkili, 2005; Leete, 2006). Peat or highly organic soils present a problematic and poor quality soil due to it's excessive compressibility, poor drainage on site (Edil, 2003; Wong et al., 2008). It is very difficult to stabilise peat due to it's very high water content and as it consists of decomposed plant fragment, lower pH and as a result it's potential to interfere chemically and biologically with time and environmental condition (Magnan, 1993; Hernandez et al., 2009). These unfavourable characteristics of peat soil deposits make them unsuitable for supporting most engineering projects or infrastructure development. Furthermore, such ground presents failure due to ground instability such as localised sinking and extreme settlement over extended time periods when subjected to a increase in loading (Jarret, 1995; Huat et al., 2004).

Common remedial practice in such instances involves mass replacement with imported materials, deep piling, installation of vertical drains, thermal precompression, laying surface reinforcement as geotextile and chemical admixture applied either as deep insitu mixing or surface stabiliser (Edil, 2003). Where possible engineers seek to avoid building on these problematic ground. Nevertheless, increasing land use makes it a growing necessity to build on these unfavourable grounds. Developing the knowledge of their geotechnical properties such as shear strength, stiffness and compressibility behaviour is needed to provide suitable design parameters for this type of ground before any construction can take place on them.

Deep mixing method relies on the introduction of a chemical binder to alter the physical properties of the soil mass. Through this process, the soil will be improved by the reduction of water content, cement hydration hardening, bonding of soil particles and filling of void by pozzolanic reaction (CDIT, 2002; Yee et al., 2007; Hebib et al., 2003).

This application was started in the late 1970's in Japan and Sweden by adding dry or wet binders in order to reduce settlements, and improve the stability and strength of soil; increase of bearing capacity, prevention of sliding failure, reduction of vibration and remediation of contaminated ground (Terashi et al., 1979; Kawasaki et al., 1981; Ahenberg et al., 1995). Due to the success of deep mixing technique worldwide, there have been various novel construction and installation technologies such as adding binders to stabilised peat and organic soils. This technique is widely adopted because it is more appropriate in term of construction and the ground can be improved very quickly (Hayashi et al., 2005). Furthermore the technique has proved to be a successful application leading to possible offers of economical design in terms of raw material and being less labour intensive. The technique also causes minimal disturbance during installation in terms of noise and vibration levels. In addition, deep mixing method is a reliable solution applicable to a wide range of soils. Hence it provides excellent quality improvement due to uniform and homogenous product quality which is controllable by counter – rotation mechanism comparison with other ground improvement methods (Hampton et al., 1998; EuroSoilStab, 2002).

Typical chemical binders used in soil stabilisation include cement, lime, fly ash or waste industrial material as stabilized agents, essentially to modify the original soil texture and properties to a stronger soil matrix (Ahnberg et al., 2005; Duraisamy, 2007; Hebib et al., 2003). As suggested by Broms (1986), in Southeast Asia, it is preferable to use cement instead of lime, because of the low cost of cement compared to lime and the greater strength which can be obtained with cement in a shorter period. Chen (2006) reported that cementatious compounds can change the composition and structure of the calcium liberated gel to form insoluble calcium humid acid, which is responsible for the increase in soil strength.

The strength of soil mixtures are influenced by various parameters like original soil character, binder type, binder dosage rate and proportion, binder water cement ratio, uniformity of soil binder mixing, specimen preparation techniques, and curing condition (Dong et al., 1996; Shen et al., 2005; Al- Tabba et al., 1999; Bhadriraju et al., 2008). Accurate estimation of laboratory mix design for selecting optimum stabiliser dosage and

proportions is thus important for successful field implementation of deep mixing method. Hence, quality assessments of laboratory stabilised soil design should be considered to ensure that strength and stiffness properties are able to meet targeted properties established and thus contribute to quality control with in situ implementation.

Previous research (Den Haan, 1997; Axelsson et al., 2002; EuroSoilStab, 2002; Janz et al., 2002; Hernandez et al., 2009) has described correlations between strength, stiffness and compressibility behaviour of peaty soil which help assess the effectiveness of using cement as stabilising agents at a particular site. This research study addresses the influence of binder amount with various water/cement ratios. As a preliminary effort it also attempts to consider parameters such as socio-economic, health-related and environmental friendliness of the method. The project presents a wide diversity of knowledge and experience in term of technology and expertise which is able to help engineers solve such problematic ground pragmatically for long term applications. The flow chart for this research is shown in Figure 1.1 and discussed research methodology in Chapter 3.

1.2 Aim and objectives of study

1.2.1 Aim

The aim of the study was to investigate the suitability of using cement as a means of revitalising peat and organic soils.

1.2.2 Objective

The objectives of this study are consequently as given below:

1. To determine geotechnical (i.e. compressibility, shear strength and stiffness) and chemical (i.e. pH) properties of revitalised organic and peat soils.
2. To investigate the effectiveness of cement as a binder on the strength and stiffness characteristic of revitalised soil.
3. To characterise the behaviour and observe the microstructure of organic/peat soils.

1.3 Research scopes

The scope of this study is to focus only on the geotechnical properties of cement revitalised peat and organic soils. Organic soils were obtained from Bukit Rambai, Malacca (MOS). Peat tested from MARDI Pontian (PP), Johor. Both disturbed soft soils were obtained at depth of about 1.5m from surface level. Ordinary Portland cement was added to PP and MOS samples at water cement ratios of 3.5, 7, 14, 140 % and 5, 10, 15 %, respectively. Relevant physical properties measured were natural water content, particle size distribution, Atterberg limits, specific gravity, organic content, ash content, fiber content and acidity according to BS 1377:1990 and ASTM, D4427.

Laboratory soil samples are prepared for simulating the mixing method. Unconfined compressive strength, bender element, consolidated undrained triaxial and one dimensional consolidation (an odeometer) tests on 7, 14 and 28 day curing samples were conducted to assess the stabilized soil properties.

'Curing' in this study means placing the specimens in a closed box with raised platforms at room temperature (25^{o}C). The box is filled with bleach solution during the curing period. The study also adopts a practical approach to addressing the effectiveness of using cement as stabilising agents in terms of strength, stiffness and compressibility. In addition, Scanning Electron Miscroscope (SEM) studies made were to observe any changes in microstructure within the revitalised soils.

1.4 Outline of thesis

The organization of the thesis is as shown below:

Chapter	Titles	Description
01	Introduction	Project introduction including aim, objective and scopes of study
02	Literature review	Reviews the literature relating to the research, which includes soil properties/ characteristics, binder properties, soil stabilisation technique, and laboratory testing theories.
03	Research methodology	Materials and experimental work in terms of sample preparation, test equipment, and procedure is described. This section discusses a developed laboratory testing technique which is considered necessary in the site for successful field implementation. This chapter attempts to provide insights into the knowledge for improving (revitalising) peaty ground.
04	Laboratory investigation	Present and analyse the test results, where soil classification, mineralogy, changes in microstructure of stabilised soils, shear strength, compressibility index and stiffness of soil are discussed in detail.
05	Discussion and correlation	Correlations between the various parameters are established and compared with results from previous researchers.
06	Conclusion and recommendation	Outlines a summary of present work and detail recommendation for future work based on current research experience and literature review. This helped to establish a new method for further practical and long term applications.
	References	A complete list of references is included
	Appendices	Appendices of relevant topics can be found in the end of the thesis.

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